Introduction and Executive Summary

The fourth NUMI Beam Instrumentation Review was held on October 24, 2003. The charge, agenda, and names of the review committee members are given in the Appendix.

The review scope included beam line instrumentation of the normal type that Fermilab has been using for many years in these applications as well as a review of the status of a new set of Profile Monitors that are capable of operating in the intense NUMI primary beam while keeping within the loss budget. The charge did not include a review of the Beam Permit System even though some of the instrumentation covered in this review will provide inputs to it. The Beam Permit System will be the subject of another review later in calendar '03.

The review committee would like to thank the speakers for the high quality of their presentations and their willingness to answer questions and to engage in discussion.

The NUMI beam is now approximately one year away from commissioning. Construction is ahead of schedule. It may well be that instrumentation is now on the critical path for being able to commission the beam. It is especially important to make sure that all instrumentation is accurately specified, adequate to the task, and that plans and resources are in place to provide fully tested devices on schedule for installation.

The pressure on the schedule is exacerbated by the access limitations in the upstream area. All equipment that goes in the upstream tunnel must be at Fermilab and tested by July 1, 2004 so that it can be installed in next summer's shutdown of accelerator operations. Equipment for the downstream area can be installed later and must be at Fermilab and fully tested by September 2004.

In general, the "conventional" beam line instrumentation seems to be in good shape but there are many open issues that are discussed below. The status of the Profile Monitors is more problematic. The task of providing them has been an ongoing project undertaken by University of Texas at Austin, with Sacha Kopp as the project leader. The goal is to provide a profile monitor that can operate for long periods of time in the NUMI beam, with low losses, and a spatial resolution of 0.2 mm for the upstream devices and 0.1 mm for the devices closest to the target. The original specification required that the device take up less than 10.25" along the beamline. Subsequent changes in the NUMI primary beam design have freed up more space and most of the locations where the profile monitors are located could accommodate larger devices. A total of 10 profile monitors and two spares were originally specified but there is a proposal to increase the number to 12 devices (plus the two spares).

With respect to the Profile Monitors, the issue before the committee is to evaluate the status of the UTA project, to consider whether a need for a fallback system exists, and, if such a need exists, to provide a recommendation on which of the possible systems should be pursued.

Key Recommendations

The committee's two key recommendations are given here. Further discussion and more detailed recommendations follow in the text below.

1. Fermilab Beams Division should rapidly identify a full-time individual to act as the NuMI beam Instrumentation Coordinator. This individual must work together with all parties and groups to assure that all instrumentation is specified, that all the required planning for construction, testing, and installation, readout and data logging are carried out, that adequate personnel are assigned to the task, and that schedules are made and followed. The Instrumentation Coordinator will insure the designs, including the profile monitors, will meet the experiment requirements and those of the beams groups. We anticipate that this individual is not just a manager, but also a person with hands-on effort.

2. Although concerned that technical issues on profile monitors still remain at this time, the committee unanimously recommends that the baseline plan be aggressively pursued with all available resources. The baseline approach appears feasible but needs the full attention of all personnel to overcome the current difficulties in order to meet the demanding schedule. The efforts of Fermilab personnel should primarily be aimed at helping the Texas group overcome the remaining technical issues and adequately demonstrate the foil SEM technology. All specifications necessary for the foil SEM design should be completed and approved by Oct 31, 2003. No further effort should be undertaken at this time on alternative new designs. A backup plan should be developed which depends on deployment of existing multi-wire designs as a temporary, short-term solution should technical uncertainties in the foil SEM design persist beyond January, 2004. A prototype foil SEM should be demonstrated to meet vacuum requirements by that time and additional evidence of the stability of the foil strips should be demonstrated. Even if technical difficulties should persist, the central focus for the foreseeable future should continue to be aimed at solving the foil SEM technical issues and deploying those devices as much and as early as practical.

Review of Technical Requirements

The Technical Requirements for the NUMI beam line are driven by the high intensity and the requirement of low losses. This leads to the need for non-interacting beam monitoring and control based on a system of Beam Position Monitors (BPMs) and of loss measurement based on small "sealed loss monitors" at many points along the beam and four "total loss monitors" that cover a large fraction of the length of the beam. The apparent position measurements of the BPMs are known to drift and must be recalibrated by a system that provides absolute measurements. For

NUMI, this will be accomplished by a system of "Beam Profile Monitors". These devices interact with the beam and will only be inserted periodically, perhaps for a few minutes every few hours or so, to provide the absolute calibration for the BPM system. They will also be inserted briefly to trouble shoot problems. The losses due to the insertion of the Profile Monitors contribute to the total NUMI beam loss budget and must be carefully controlled. This leads to requirements on the vacuum of the Profile Monitor enclosure, on the thickness of the profile measuring elements, and the requirement to have an open geometry with no frame on the side that moves through the beam. Profile Monitors used in high intensity beams have used Secondary Emission from wires or foils. The intense beam can also cause ageing of the detector elements.

Beam characteristics and high-level requirements seem to be well-understood and clearly stated. Translation to instrument specifications generally have solid justification. However, there are instaances where the specifications are not complete.

Review of "conventional beam instrumentation"

Schedule

July 1, ‘04 is the date when all instrumentation that goes in the upstream section needs to be at FNAL, tested, and ready to install.

September 1, ‘04 is the date when all instrumentation that goes in the downstream section needs to be at FNAL, tested, and ready to install.

A schedule was shown for the BPM system. No comprehensive schedule for production and testing of all the remaining conventional components was shown.

Specifications

Several specifications seem to be missing, not finalized, not widely disseminated, or not accepted as achievable by some stakeholders.

BPMs

Non-interacting detectors, i.e. the BPMs, are required to provide continuous monitoring of the beam position in order to keep beam loss low. The Profile Monitors are required to calibrate the position measurement of the BPMs. This will need to be done every few hours (not clearly specified).

The BPM electronics for NUMI will follow the design of the Recycler System. The system has performed well in the Recycler and MiniBooNe beam line. The Beams Division Instrumentation Department is not

convinced that they can meet the long term (period of hours) resolution and stability requirements of 150 microns for 1E10 protons/bunch averaged over a full spill.

The position of the beam on the target is monitored and controlled by two sets of well-separated BPMs. The spot size of the beam is not directly measured since there are no profile monitors very close to the target. The beam size on the target is monitored by various indirect methods. Some committee members thought that this was not adequate.

The BPM position measurement is calibrated by occasionally inserting nearby Profile Monitors. The calibration of the few BPMs that are not near Profile Monitors is accomplished by indirect means. Again, some committee members worried that the desired calibration accuracy would be difficult to achieve.

The total number of BPMs is 34. Four are in the Main Injector. Twenty-six are in the beam line and there are the four (near to the) target BPMs mentioned above. Most of these exist. This is a large project. The cost of the major components of the electronics (not including the detectors or cables) is estimated to be $188K. Many parts have been ordered and for others, purchase orders have been submitted.

Toroids

The two toroids will monitor the proton beam intensity and are currently expected to have an accuracy of +/-3%. We do not know where this specification came from, whether it is achievable, or whether it is adequate to the needs of the experiment for normalization.

Resistive Wall Monitor

There is no resistive wall monitor in the current baseline plan but one is under consideration. It would provide information on the individual proton bunches and batches and would provide information on kicker failures.

Temperature/Humidity Sensors

These are standard instrumentation and the specifications, number, and location seem to be well understood. There are provisions for 16 temperature and 16 humidity sensors.

Loss Monitors

Loss monitors are a key element of the operation of the NUMI beam. We did not see a definite plan that assured that the loss monitors would be working, that is a heartbeat. We did not see that the

high voltage or gas flow to the loss monitors is monitored. There is a proposal to put a source in the total (long) loss monitors but we weren't sure exactly how this would work. The use of 7/8" heliax rather than 1 5/8" (standard at FNAL) was a source of possible concern to some committee members.

There is only one vendor for sealed loss monitors. Twenty-four are in hand but deliveries stopped for a while. They are starting up again and the company can deliver 8/week. Sixty are required for NUMI. A total of 250 have been ordered for general purposes. NUMI obviously has the highest priority for these and will get the next deliveries until it has its full complement. The Instrumentation Department is trying to develop a second source for these.

Personnel

We saw names of people in the Instrumentation Department listed next to many of the tasks. We want to be sure that these people are really available, even in light of competing demands, and that their supervisors understand and accept this.

Cabling

We were unclear whether all cabling needs had been accounted for and scheduled for installation. We could not tell who had the responsibility to make sure that all this work got done.

Software and Data Logging

We could not get a good picture of MINOS' requirements for logging data from the primary beam system. There is someone working on getting these from ACNET but no one was sure how extensive the work is.

There was general concern that software effort had not been taken into account fully and not enough will be available for the project.

Configuration Management

A configuration management procedure is in place but it needs to be applied more rigorously. There seems to be no official "schematic" of the beam showing instrumentation (although there seem to be "unofficial" ones) and having brief statements of the key characteristics of devices. A beam sheet exists and is supposed to be updated as needed. There seems to be a lag between the time when changes are decided upon and when they are reflected in the official plan. It is not clear that this information is actually reviewed by all stakeholders. In particular, it is not clear whether the MINOS experiment pays attention to changes.

Recommendations

All specifications should be completed and should be clearly documented as soon as possible. Changes should be reflected in formal updates and should be transmitted to all affected parties, including the MINOS experiment.

A detailed, reviewable plan for determining that the beam position and beam focus at the target is within "acceptable" limits should be written.

A resistive wall monitor should be included in the beam instrumentation.

The Beams Division and the NUMI team should agree on the specifications for the BPM accuracy.

The Beams Division, the NUMI team, and the MINOS experiment should agree on the specification for the Toroid accuracy.

Careful attention must be paid to insure deliveries of sealed loss monitors from the existing vendor. A plan should be developed to demonstrate that the loss monitors are working. For the total loss monitors, this could be accomplished with sources. The voltage for all loss monitors and gas flow of the total loss monitors should probably be monitored.

The Instrumentation Department should evaluate whether it has the personnel to meet the NUMI installation schedule in light of competing demands, especially from Run 2, which has higher priority than NUMI.

The software requirements for all support of the instrumentation and for data logging should be determined. The availability of personnel to implement the requirements must be determined. In particular, if there are demands on the Beams Division Controls Department, the Controls Department should evaluate whether it has the personnel to satisfy these requirements in light of competing demands, especially from Run 2, which has higher priority than NUMI.

A comprehensive schedule for all the work to produce, bench test, install, and "test in place" the required instrumentation should be developed. Personnel requirements should be specified, and a specific person should be assigned to each task.

The committee recommends the appointment of an Instrumentation Coordinator whose job is to make sure that all the diverse elements of this project come together in time to meet the demands on instrumentation of NUMI commissioning. This recommendation is reinforced by the particular instance of Beam Profile Monitors, covered in the next section.

Review of the Beam Profile Monitor System

The Profile Monitor system differs from the other systems, in that it involves R&D. The work is being carried out by the group at University of Texas at Austin, led by Sacha Kopp. The proposed system is based on Secondary Emission from Foils and will be abbreviated as FS. The foils are 5 micron thick titanium and scatter the beam much less than the 75 micron diameter gold-plated tungsten/rhenium(3%) with 1 mm spacing used in standard Fermilab multi-wire SEMs. There is concern at this time that the work is behind schedule and may not be ready to meet the deadline for installation, especially the July 1, '04 date for tested systems for the upstream Profile Monitors to be available at Fermilab for installation.

The baseline system calls for 10 FS from Texas. An addition to the scope of two "conventional" Fermilab "multi-wires" with 1 mm spacing by 3 mil wire diameter is apparently under consideration. These profile monitors are in standard cylindrical vacuum cans. Readout for both systems is via FNAL-supplied "SWIC scanners" and motion control is through FNAL standard motion controllers. The UTA team has spent significant effort understanding these systems and how to interface to them. Fermilab will also supply all the cables, survey, and possibly help with fiducialization.

The issue before the committee is to evaluate the status of the UTA project, to consider whether a need for a fallback system exists, and, if such a need exists, to provide a recommendation on which of the possible systems should be pursued.

Without dwelling on ancient history or apportioning blame, the committee is fully convinced that serious communications problems have affected the rate of progress on this project, and if not corrected, could threaten its success.

The Status of the University of Texas effort

The committee was rather distressed to learn that, even at this late date, not all specifications have been finalized. Open specifications seem to include the requirement on vacuum (10^{-8} with a 30 l/sec ion pump), diameter of FNAL quick disconnects, total mass, radiation resistance, various issues related to the alignment of foils, and the duration of time required to move the foils in and out of the beam.

Sacha stated that lack of response concerning the specifications has caused significant delays in the project.

The specification for the length of the system along the beam line is 10.25". However, since the redesign of the primary beam transport, now nearly a year old, this is no longer applicable to most of the locations where profile monitors are needed.

The requirement of "longevity to 10^{20} protons/cm^2" is probably misstated. The actual fluence is probably much higher for the devices nearest the target but, since they only need to be in the beam a small fraction of the time, the specification is the maximum fluence times the duty factor. The actual number should be pinned down, especially if it is different for devices in the target area versus upstream devices.

The UTA design has an open-sided system of very thin secondary emitting foils strips mounted in a bayonet-style can. To the extent that the requirements are understood, this system appears to have the potential to satisfy them. The system also has the possibility of operating for long periods of time in the beam due to the low mass of the foils and of providing "halo information" by ganging together several strips outside the actual beam region.

The testing of the first prototype system at Fermilab was sort of a mess. There was a vacuum leak, which may have been present when the system was shipped or may have been created during testing at FNAL. Whatever source of the problems, the opportunity to demonstrate progress that would have lowered the perception of risk was missed.

The various concerns about the system were extensively discussed. We attempt to summarize them.

The FS uses a bayonet-type vacuum box. There are concerns about the vacuum system - outgassing of materials and presence of virtual leaks, that have only intensified since a prototype system sent to Fermilab did not meet its requirements. Since then, several improvements have been made, and it is believed that the system should achieve close to 10^{-8} torr. The use of PEEK in the system may be a source of some of the vacuum problems. Fermilab Beams Division Mechanical Support Department personnel have some experience with this material and the UTA physicists should be sure to take advantage of this. Committee members were concerned about whether the Profile Monitor could survive the vacuum certification process, which includes bake-out.

There are concerns about the stability of the foils. The foils could be subjected to a variety of vibrations during transport, installation, and operation. There is the possibility of some kind of pressure surge in the beam pipe if there is a vacuum failure or if the system has to be let up to atmosphere for servicing.

There are concerns about the fiducialization of the strips. The concern was not that this would be a show stopper but that it might be harder to achieve than now believed and that adequate time be allowed in the schedule to accomplish it.

There were concerns that the overall weight of the system would make it more likely that vacuum leaks would develop during installation. The committee felt that this could be dealt with by providing an appropriate transportation and installation fixture.

There were concerns about long-term support for the devices once delivered. Since Fermilab has many arrangements with vendors and experimenters to share maintenance for equipment produced elsewhere, the committee does not regard this as a fundamental problem. The UTA group plans to provide maintenance, or at least expert backup to local maintenance by Fermilab, for a long period of time and to transfer the knowledge to Fermilab. Fermilab will have to provide the personnel to learn the new system and to do the maintenance. The actual arrangement has not been worked out and probably requires an MOU between UTA and Beams Division.

Concerns about the schedule and about production capacity at UT Austin are key to this discussion. The first six systems need to be at Fermilab and tested by July 1, '04 and the remaining four and the two spares by Sept 1, '04. Given that there is no final, proven design, this is a very real issue.

A schedule was presented that looks feasible, if the next round of vacuum work is successful. Some purchases of long lead-time items have already occurred. The costs seem to be firmly established. The group seems to be committed and to have marshaled the resources they need.

Need for a Fallback position

However, because of the lack of a successful prototype and the fact that schedules up to now have NOT been met, the committee agrees that there is risk to the NUMI commissioning and that a fallback position is required.

Next steps and milestones

New information will be available in mid-November and January. In November, the first prototype will begin operation in the MiniBooNE beam. While the resolution has been compromised due to damage that has occurred to the foil, many other properties of the device can be studied. It is our understanding that after rework at Fermilab, the vacuum can now is close to meeting the specification.

In January, the next prototype will be delivered at FNAL. This system should be capable of meeting the specifications. If this system is delayed or fails to meet its goals, this would trigger the implementation of a fallback system.

The Proposed Fallbacks

Partial Fallback Plan

The "partial fallback" plan, proposed by Sam Childress and members of the Fermilab Beams Division Instrumentation Department consists of:

1. replacing 5 FS devices in the upstream part of the beam with 5 "modified" Fermilab multi-wires;

2. replacing the device called PM111, formerly a Fermilab multi-wire, with a UT linear drive containing a “foil-target” assembly. This appears to be new scope recently added to the project and not known to the UTA people. Its purpose is to create a controlled source of losses for calibration purposes;
3. using for the 6 devices in the downstream section UTA Foils mounted in a Fermilab cylindrical vacuum can; and
4. using for the fourth device in this group, however, a linear UTA drive with a foil-target assembly. This is also a recent change.

The modifications proposed to be made to the "standard" multi-wires are

1. To reduce the wire diameter from 3 mils to 1 mil to reduce beam loss;
2. To design an open-sided wire plane to permit live insertion and retraction of the multi-wires. This involves a ceramic frame with pads at 45^{o}. There is a cut in the frame and the frame must be pre-stressed;
3. To add 5 micron thick bias foils with beam clearance holes;
4. To design a stand to accommodate the 45^{o} mounting that will be required;
5. To verify that the positioning system has 50 micron repeatability; and
6. To provide a cost estimate and personnel estimate.

This looks like a significant amount of work, but some part of it appears to have been underway so that some issues are already at least partially resolved.

However, there are additional R&D issues for UTA to implement their part of this design.

UTA will apparently have to obtain the designs and procure 5 + 1 spare FNAL cylindrical cans (No one on the committee understood why these cans would not be provided to UTA by Fermilab). Then, they would need to learn how to support the foils in this can and would have to check various mechanical issues, such as repeatability and stability under the rotational motion of the FNAL drive arrangement. Moreover, UTA would still need to make the two linear drive cans.

Under technical risk, it was observed that UT might have a very difficult time designing a foil SEM Profile Monitor compatible with constraints of Fermilab vacuum can.

The unanimous judgment of the review committee, looking at all the work involved, is that this is another R&D project and not a genuine fallback position. Since it is believed that the vacuum problem, the main issue that this solution addresses, is probably solved, this proposal doesn't even address some of the most serious remaining problems.

The Full FALLBACK and its implications for NUMI Operation

The committee requested an assessment of the consequences of using the standard Fermilab multi-wire without modification as a fallback. This requires no R&D.

It was declared to be workable but has implications for operations. The beam has to be "turned off" (i.e. not extracted) while the multi-wires are being moved in. This is because, without modification, the wire plane

has a frame that will pass through the beam and produce unacceptable losses. This will have some implications for controls and the permit system. The amount of time the device can be left in the beam may be limited because it has more material. Ageing might cause the need for more frequent replacement.

The MINOS experiment needs to consider whether these constraints, which could cause some reduction in the number of integrated beam spills, are acceptable in the event that the UTA system cannot be made to work.

Note: The repeatability of 50 microns with wires seems to be established. We did not understand whether bias foils would be needed for this system. We also heard that it would be easy and simple to change the wire thickness from 3 mils to 2 mils to reduce beam loss.

Discussion

The current baseline system is the best system for NUMI operation. The completion of the system will be a challenge and needs the efforts of both the UTA team and personnel at Fermilab. The proposed Plan B, which we refer to as a "partial fallback" has R&D issues for both Fermilab and UTA. It is not the kind of "sure thing" that qualifies as a genuine fallback and could be more risky than the current baseline. There exists a true fallback, even though it leads to some constraints on operations.

Recommendations

Although concerned that technical issues on profile monitors still remain at this time, the committee unanimously recommends that the baseline plan be aggressively pursued with all available resources. The baseline approach appears feasible but needs the full attention of all personnel to overcome the current difficulties in order to meet the demanding schedule. The efforts of Fermilab personnel should primarily be aimed at helping the Texas group overcome the remaining technical issues and adequately demonstrate the foil SEM technology. All specifications necessary for the foil SEM design should be completed and approved by Oct 31, 2003. No further effort should be undertaken at this time on alternative new designs. A backup plan should be developed that depends on deployment of existing multi-wire designs as a temporary, short-term solution should technical uncertainties in the foil SEM design persist beyond January, 2004. A prototype foil SEM should be demonstrated to meet vacuum requirements by that time and additional evidence of the stability of the foil strips should be demonstrated. Even if technical difficulties should persist, the central focus for the foreseeable future should continue to be aimed at solving the foil SEM technical issues and deploying those devices as much and as early as practical.

The committee recommends that there be a close cooperation between the Fermilab vacuum experts and the UTA group to review designs to help eliminate subtle problems like virtual leaks.

If outgassing due to materials is still considered to be a problem, the committee encourages UTA to do a test with a vacuum can and a mockup of its contents, with the PEEK replaced with a ceramic material.

We strongly recommend that the objectives of tests be carefully written down, and that the tests be highly coordinated so that everyone accepts the results. It would be best if a UTA team member could accompany the test system and participate in the tests. When the Instrumentation Coordinator is in place, he/she should superintend the testing.

We recommend that UTA and the appropriate support departments in the Beams Division develop an MOU that specifies the support plan for these devices and includes as deliverables from UTA, along with the devices, full documentation of the device design.

Finally, we note that the Instrumentation Coordinator is expected to eliminate the communications problems that have affected the development of this system. That recommendation is as applicable to this section as to the section on "conventional" instrumentation.

Appendix

COMMITTEE CHARGE

The committee is requested to assess whether the technical, resource and schedule aspects of instrumentation is sufficiently developed to commission the NuMI beamline in January 2005. This is the fourth instrumentation review. The committee is also requested to address the following specific questions:

1. Are the specifications defined and founded on a good technical basis?
2. Do all sub-systems have a clearly defined project manager and resource loaded schedule? Are there clearly defined milestones for key tasks?
3. Are BD Instrumentation Dept resources sufficient to complete NUMI instrumentation and have it completely checked out and operational on schedule for commissioning while meeting other program instrumentation needs?
4. Is a parallel design path for the beam profile monitor advisable? Is there sufficient technical and resource confidence in 1) the "thin multi-wire" design or the "thin foil" design and 2) the "rotary insertion" design or the "bayonet insertion" design to warrant an immediate decision?

The committee should note that the interface between beam instrumentation and the NuMI Beam Permit System will be addressed in a future review and need not be considered here.

CHARGE TO THE COMMITTEE CHAIR

The committee chair is requested to write a report consisting of a very short summary and a list of recommendations.

Agenda

8:30 - 8:45 Closed Session
8:45 - 10:00 Technical Requirements - Childress
10:00 - 10:15 Break
10:15 - 11:30 Instrumentation Dept Plans - Crisp
11:30 - 12:00 Closed Session

1:00 - 1:15 Closed Session
1:15 - 2:30 UT-Austin profile monitor - Kopp
2:30 - 2:45 Break
2:45 - 4:00 FNAL profile monitor - Webber (for Tassotto)
4:00 - 4:30 Closed Session

Reviewers

Paul Czarapata ,
Rick Ford,
Peter Garbincius,
Jim Hylen,
Cary Kendziora,
Alberto Marchionni,
Doug Michael,
Linda Stutte,
Joel N． Butler (chair)